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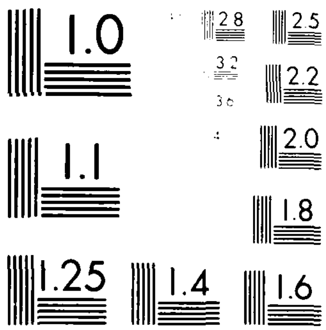
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REPORT SD-TR-86-42

Picosecond Optoelectronic Diagnostics of Field Effect Transistors

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86

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This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The frequency-dependent scattering parameters of an unpackaged GaAs field effect transistor have been measured using picosecond optoelectronic diagnostic techniques. The large bandwidth available and simple de-embedding procedures make these techniques very promising for characterization of devices operating in the millimeter-wave region.

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CONTENTS

A-1

FIGURES

I. INTRODUCTION

Picosecond optoelectronics provides the capability to measure the frequency response of solid state devices with much greater bandwidth than conventional techniques. Laser-triggered switches act as pulse generators and samplers to measure the impulse response of a device with a temporal resolution of a few picoseconds. Fourier analysis of the impulse response functions yields scattering matrix parameters with a frequency bandwidth of 40 GHz or more. In comparison, current frequency-domain technology is limited to a 26 GHz bandwidth. (Higher frequencies can be covered with frequency mixing techniques at the cost of additional noise and experimental complexity).

The electrical properties of a linear device can be completely characterized by time-domain measurements of the impulse response. These data can be Fourier transformed to yield frequency-domain information. For a two-port device, the Fourier transform of the impulse response is the device transfer function, which is equivalent to the S_{21} scattering parameter. Similarly, the response at the input port when the output port is pulsed yields the S_{12} parameter, and the reflection of a pulse off the input or the output port transforms into the S_{11} or S_{22} parameters. These data are equivalent to those obtained from a network analyzer, with the advantage of greater frequency bandwidth. In addition, the de-embedding process is considerably simplified because the pulses are generated and sampled within a few millimeters of the device being characterized. The only intervening elements (other than the bond wires) are short sections of easily characterized transmission line.[1] Windowing of the time-domain response can also enhance the de-embedding process by separating the device response from artifacts due to the test fixture. In this report we apply picosecond optoelectronic techniques to the characterization of an unpackaged GaAs field effect transistor (FET).

[1] D. E. Cooper, "Picosecond Optoelectronic Measurement of Microstrip Dispersion," Appl. Phys. Lett. 47, 33 (1985).

II. EXPERIMENTAL

Optoelectronic pulse generators and samplers were fabricated in microstrip transmission lines on silicon-on-sapphire (SOS) substrates.[2] Two test fixture designs were used (Fig. 1). In the split fixture (Fig. 1a), two separate SOS wafers were connected by a gold-plated Kovar strip attached to each ground plane with conducting epoxy. The device under study was epoxied to the Kovar strip in the ~1 mm gap between wafers and wire bonded to the microstrips and the ground plane. A second test fixture design was used to simplify fixture fabrication and reduce the inductance of the source bond wires. This design (Fig. 1b) was fabricated on a single SOS wafer with the source connection to two large, relatively low impedance pads. The microstrip impedance in both test fixtures was approximately 50 Ω.

The optoelectronic pulse generation and sampling switches were triggered by 4 ps optical pulses from a synchronously pumped dye laser. A 6-7 ps electrical pulse from a biased switch entered one port and was sampled at the same or the other port by triggering a sampling switch with a second time-delayed optical pulse. The current conducted across the sampling switch was measured as a function of time delay to produce the impulse response function. The operating point of the device under test was controlled by dc voltages applied to the gate and drain microstrips.

[2] P. R. Smith, D. H. Auston, A. M. Johnson, and W. M. Augustyniak, Appl. Phys. Lett. 38, 47 (1981).

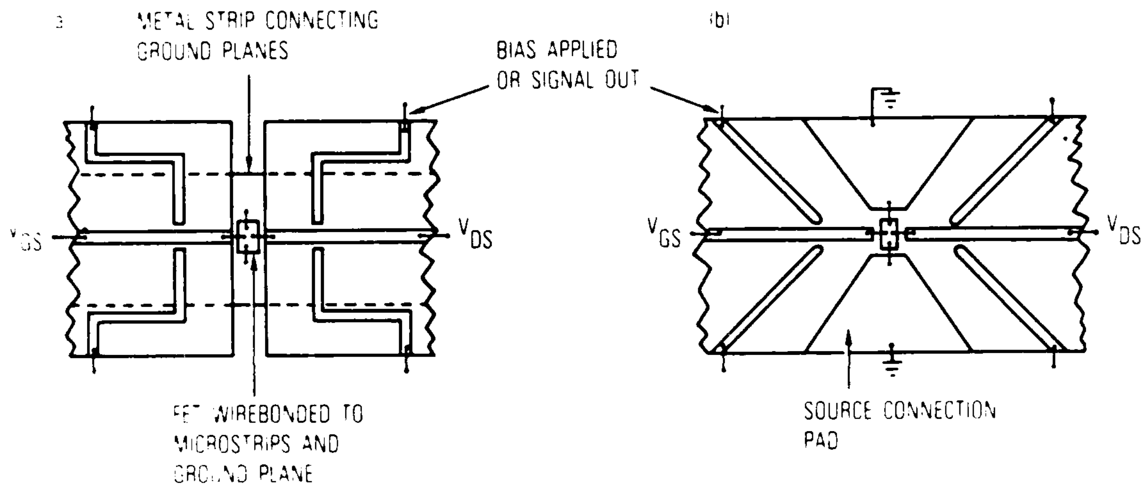

Fig. 1. Experimental Test Fixtures

III. RESULTS AND DISCUSSION

The impulse response of an Avantek AT-8041 in the split fixture is shown in Fig. 2. Figure 2a and 2d exhibit the result of reflecting an electrical pulse off the gate and the drain, respectively. For these measurements the pulses are generated at one port of the device, and sampling is done at the same port immediately opposite the pulse generation switch. Thus the large initial peak represents the profile of the pulse entering the device, the shoulder is the result of the reflection at the wire bond to the microstrip, and the broad peak at later times is the reflection from the device itself. The rapid oscillations at the right of the trace are an experimental artifact resulting from reflections in the microstrip circuit. Because of the congested nature of these data, the actual pulse reflections are difficult to extract, and the second test fixture was designed to minimize these problems. Figure 2b reveals the gate response when the drain is pulsed, and Fig. 2c reveals the drain response when the gate is pulsed. These data are quite clean and easy to interpret. Figure 2c exhibits a 10-90% rise time of 8.2 ps when the transistor is used as an amplifier, with a longer tail indicating considerable phase dispersion within the FET. This very rapid rise is close to the temporal resolution of the test fixture. These data were digitized, and a fast Fourier transform was performed on a microcomputer. The pulse shape and sampling aperture were deconvoluted by dividing the transformed spectrum by the spectrum of an optoelectronic "autocorrelation" peak. The result is the S_{21} spectrum displayed in Fig. 3. The fit to the expected f^{-1} dependence at high frequencies is reasonably good. The switch sensitivities were not calibrated for these measurements, so the absolute gain is not known, but the data are well behaved out to a 40 GHz bandwidth.

The planar test fixture produced impulse response data that were significantly different from the split fixture. The measurements involving reflected pulses produced much cleaner data, from which S_{11} and S_{22} could be extracted. The pulse amplification experiment yielded a pulse shape with considerably longer 10-90% rise time (15 ps) and much less asymmetry. The

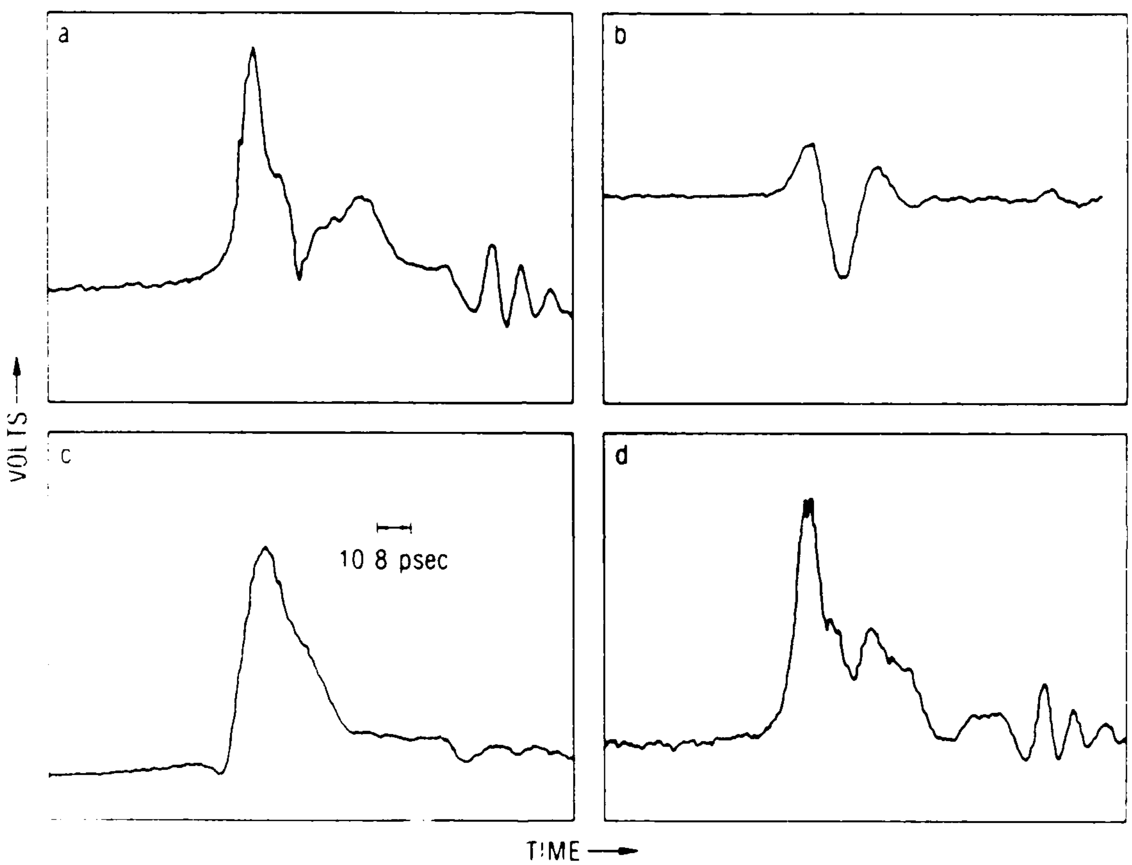

Fig. 2. Impulse Response of GaAs FET in Split Test Fixture

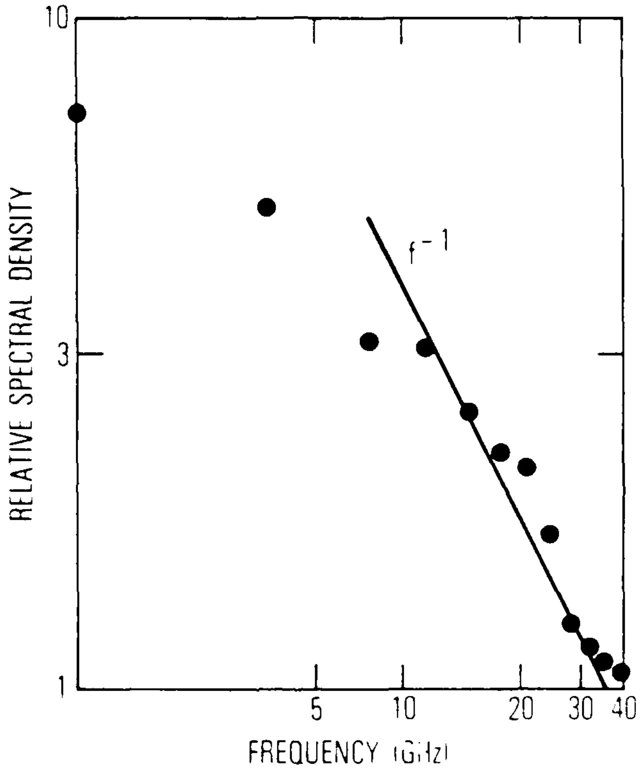

Fig. 3. Insertion Gain ($|S_{21}|$) vs. Frequency, Split Test Fixture

second test fixture used shorter source bond wires, reducing source inductance, but the low-frequency impedance of the transmission line formed by the source pads was about 25 Ω, considerably raising source resistance. These changes can be expected to have a major effect on the measured S parameters.

The data were digitized and transformed to the frequency domain, and a polar plot of S_{21} is shown in Fig. 4, with the manufacturer's S_{21} specifications shown as open circles. The input and output amplitudes were measured to yield absolute S_{21} magnitudes. This plot also exhibits the phase components of S_{21}, which depend upon the designated time origin of the pulse profile. The propagation delay of the short lengths of microstrip between the switches and wire bonds on either side of the FET was mathematically removed (de-embedded) to bring the reference plane up to the wire bond/microstrip junction. (The microstrip propagation delay was measured in a separate experiment.) This results in a very good fit to the manufacturer's specifications, with the somewhat lower gain probably the result of large source resistance. Beyond 20 GHz, the data curve continues in a smooth fashion, with a complicated resonance around 50 GHz because of the two bond wire quarter-wave resonances. The data are well above the noise level to nearly 70 GHz.

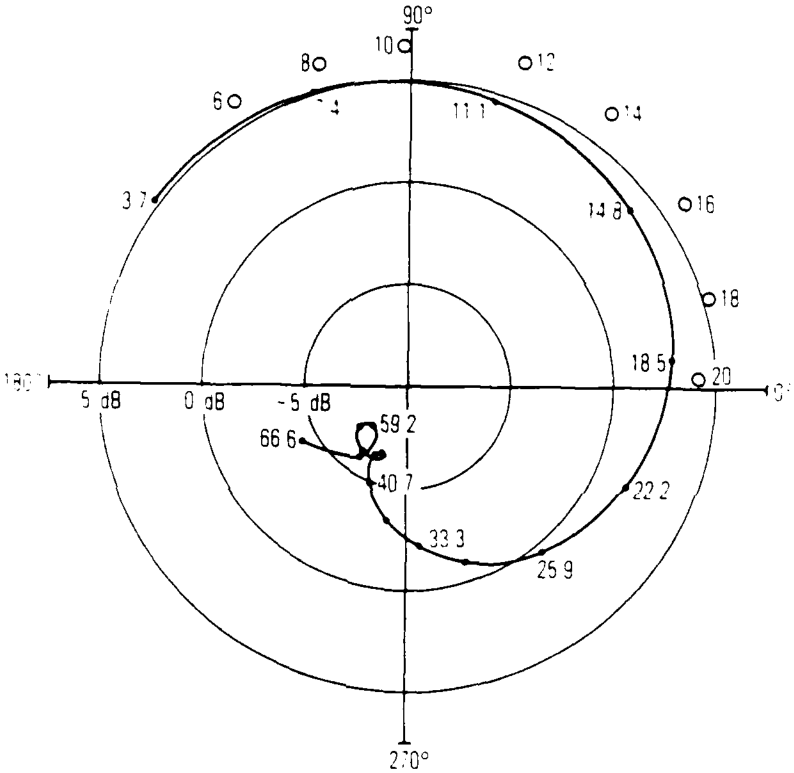

Fig. 4. Polar Plot of S_{21}, Planar Test Fixture

IV. SUMMARY

Picosecond optoelectronics provides a useful tool for high-frequency diagnostics of fast solid state devices. Linear scattering parameters are extracted from impulse response measurements, with greater bandwidth than conventional network analyzers and very simple de-embedding procedures. The process was illustrated by the picosecond optoelectronic measurement of the scattering parameters of a GaAs FET.

LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security projects, specializing in advanced military space systems. Providing research support, the corporation's Laboratory Operations conducts experimental and theoretical investigations that focus on the application of scientific and technical advances to such systems. Vital to the success of these investigations is the technical staff's wide-ranging expertise and its ability to stay current with new developments. This expertise is enhanced by a research program aimed at dealing with the many problems associated with rapidly evolving space systems. Contributing their capabilities to the research effort are these individual laboratories:

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Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, sensor out-of-field-of-view rejection, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, microelectronics applications, communication protocols, and computer security.

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